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## TASK OBJECTIVES

During the second half of 1997, we concentrated on code delivery. We were also very active in preparation for validation related activities. Algorithm testing and refinement continued with Landsat TM image, AVHRR image, and SeaWifs image data sets. We also were involved in field-based prototype validation activities. Specific objectives and tasks included:

- complete version 2 code for the vegetation index products;
- level 3 algorithm testing and BRDF integration into the level 3 compositing algorithms;
- exercise VI compositing algorithms with the daily, 1km AVHRR data stream;
- exercise VI compositing algorithms with the daily, 8 km SeaWiFS data stream;
- anticipate at launch QA and MODIS data analysis, including software tools and network issues;
- work on high speed internet connections and data flow rates.

## WORK ACCOMPLISHED

### 1. Level 3 Vegetation Index Compositing Algorithm

PGE 25 (MOD13A - NDVI at 250 m and 16 day resolutions) was delivered to SDST in collaboration with GSFC on November 18. PGE 25- MOD13B - NDVI and EVI at 1km and 16 day resolution is currently due to be delivered the second half of January 1998. The other PGEs, involving climate modeling grid products, will be delivered within a few weeks. These include PGE 26 - MOD13C - NDVI and EVI at 1km and monthly resolutions; PGE 27 - MOD13D - NDVI and EVI at climate modeling grid (CMG - 25km) and 16 day resolutions; MOD13E - PGE 28 - NDVI and EVI at CMG and monthly resolutions. The algorithms for the five vegetation index products have been frozen although slight changes may still be implemented.

The MODIS 1 km aggregation file specification was baselined in June/July 1997 in collaboration with Boston University and

University of Montana and further adjusted to include the MODLAND mandatory QA in November 1997. Our 16 day - 1 km VI product will use the aggregated reflectance product as an input. The MOD 13 VI code underwent further redesign to facilitate easier code maintenance, debugging and algorithm updates. The handling of quality assurance flags in the algorithms dealing with the input and output files were tested thoroughly using a range of possible scenarios, e.g. missing data, missing QA flags, compositing of multiple quality flags.

Sixteen days of daily 1 km AVHRR data were received from EROS Data Center (EDC; about 100 CDs with data from the western hemisphere) to work on vegetation index algorithm development and evaluate the MODIS algorithm with respect to possible artifacts. Since the daily data came without a cloud mask, the CLAVR cloud-mask was successfully adjusted and applied to the 1 km data set. The MODIS compositing algorithm code has been adjusted to work with the 1 km daily data. Currently the vegetation index composite results for the 1 km AVHRR data are being evaluated. A total of 28 days of atmospherically corrected SeaWiFS data was also received from GSFC. Some cloud testing was done to develop a cloudmask for this data, since the MODIS VI composite algorithm requires a cloudmask. Software to process these data are under developement.

A QA flag translation tool was developed for the MODIS 1km VI product. This translation tool will read a 16 bit unsigned integer and will list for each pixel what the exact QA conditions are in a descriptive format. This tool is being set up to incorporate visualization tools to graphically display specific QA conditions. A QA document was drafted to anticipate the validation and QA needs for MOD13 products and direct the SCF development. It is envisioned that the QA and validation efforts will be strung together to make efficient use of limited resources (personnel and hardware) at the SCF. In summary the QA and validation efforts will consist of:

- in depth QA analysis of 1 land tile per composite period requiring access to all input files (chosen from the validation site list),
- continuous QA and trend analysis for 50 validation sites using subsets of up to 50 land tiles,
- QA analysis of spatially continuous data on a global scale (4 times per year),

- Ad hoc QA analysis of land tiles based on LDOPE or MODLAND team findings.

## 2. Validation Activities

2.1 SWAMP- Validation Workshop, Dec. 3-5, 1997; College Park, Maryland.

A break-out working group was formed to start preliminary coordination plans relevant to the 'Biophysical/Vegetation Validation Measurements'. Betty Walter-Shea and myself co-chaired the session and wrote up a summary report. The purpose of this working group was to discuss the relevant issues in need of attention to initiate a working design and protocol for the validation of the LAI, FPAR, Land Cover, NPP, and Vegetation Index products. The goal is to develop a set of "standardized" procedures for the validation of vegetation-related satellite products across a global range of biomes, over the entire phenologic cycle, and within expected sun-target-sensor conditions. A standardized methodology is considered essential for cross-site comparability. Crucial to all of the measures discussed below is the need for ground to air to satellite registration with GPS.

For each of the vegetation products we defined relevant terms and discussed instrumentation, spatial and temporal sampling configurations, cross-calibration of field instrumentation, and additional as well as complimentary measurements needed for effective characterization of the vegetation canopy and matrix/background. We further went through the primary 'community' validation core sites and foreign tower sites and went through the measurements to be conducted at each site. We also mention the use of light aircraft for rapid, inexpensive deployment, and quick turn-around of validation data. The summary report is included as Appendix A.

2.2 Report on validation progress; PROVE experiments

In September, 1997, aircraft-mounted radiometers were used to collect bidirectional reflectance data from Walker Branch Watershed in Tennessee. The objective of this campaign was to prototype MODIS validation activities for dense forest regions. Two radiometers were used for this purpose. One was always looking nadir. The other was looking at 15 degree, 30 degree and 45 degree off-nadir angles during the over-flights. Flight lines were set at principal and orthogonal planes. Both forward and backscatter data were collected. The field of view (fov) for both radiometers were 1 degree. Ground radiometric data, fAPAR and LAI data were also collected from the same plots. Also, aircraft-based radiometric data were collected from Pecan stands near Tucson to test the effects of 1 degree and 15 degree radiometer fov on bidirectional reflectance of dense vegetation.

The lessons learned during La Jornada and Walker Branch prototype experiments were:

1. Low flying aircraft is suitable for MODIS scale reflectance data collection.
2. One degree radiometric FOV depicts surface BRDF structure better, which is important for validating MODIS non-nadir pixels.
3. Surface reflectance characterization is needed for different solar zenith angles.
4. VI-biophysical relations have to be biome-specific in order to fully relate the MODIS signals to vegetation conditions.

Based on these campaigns, we developed a cheap and easy ‘MODIS radiometric validation’ package and protocol using low-flying aircraft. Three radiometers having four MODIS-like bands each (blue, green, red and NIR), can be flown aboard any low-flying aircraft (like Cessna-180 or 185). Two of these radiometers can be off-nadir, with different view angles and the third one will always be nadir. A laptop computer aboard will control the view angles and data acquisition frequency of all three radiometers. This arrangement will be sufficient to collect data over any terrain at a scale of 250m, 500m and 1 km or more, i.e., at MODIS scale. Since the aircraft will be flown at a very low altitude (~150 - 200m above ground), the resulting radiometric data will not need any atmospheric correction. This whole package would cost only about $25,000 and can be shipped anywhere in the world and flown aboard any local airplane. This will provide flexibility for field data collection for any investigator. Details of the design and protocol of this instrument package will also be submitted as a manuscript for publication.

Faiz Rahman attended a workshop on November 19 (Grassland PROVE meeting) in Denver, Colorado. The primary goals of this workshop were to: (1) Foster collaborations of ideas/data for "higher level" analyses (e.g., product scaling to AVHRR/MODIS/POLDER resolution, biogeochemistry and/or land cover-land use change modeling); (2) Assess "lessons learned" for communicating to EOS Validation meeting (3-5 Dec. '97); and (3) discuss publication of a PROVE special issue of a journal. This meeting was attended by the participants of Jornada May '97 experiment (Grassland PROVE). The title of his talk was "Airborne radiometry for MODIS VI-Biophysical validation: Jornada Prototype Experiment".

As a simulation activity of MODIS VI-biophysical validation, existing AVIRIS data from different LTER sites are being used. Three sites, i.e., Jornada, Harvard Forest and Hubbard Brook are currently being investigated. LAI and fAPAR values of these sites are available from the LTER network. AVIRIS imagery of these sites are being used to simulate different MODIS bands. After proper atmospheric correction, the relation between derived MODIS VIs (NDVI and EVI) and LAI and fAPAR will be studied.

## 3. LBA - Ecology workshop

With most of MODLAND as co-investigators, I submitted a no-cost proposal to LBA-ecology to conduct MODIS validation activities over the LBA primary tower sites. In being selected to the LBA science team, I attended the first LBA Workshop, held in Miami, Dec. 15-18, 1997. There is great interest among the team for MODIS and other sensor data sets. Most of the remote sensing requirements for LBA-ecology are for land surface classification & characterization with secondary interest in direct parameterization (LAI). The fire intensity and occurrence, LAI/fPAR, vegetation index, NPP, and land cover products are of particular interest. In general, it is hoped that with remote sensing data, one could estimate the extent of secondary regrowth as well as burning and clearing and, in conjunction with models, extrapolate field and tower measures to the Basin scale. Most of the team consist of carbon-modelers and land use/land use change scientists. The other funded areas, but with fewer people, included the water quality and nutrient cycling groups.

Some of the key issues that need MODLAND attention are described below:

- **Training and Education**

MODIS should provide an Education and Training program designed to create users and be long-lasting (train professors and they in turn teach the students, hence the multiplier effect). Other options include the use of short courses, exchange of Post-docs and students (send Brasil Post-Docs or students to respective MODIS SCF's/labs for training for short 1-3 month periods), and technology transfer.

One idea is to hold a training workshop on MODIS (or EOS) products which would include their usage and theoretical background. The goal would be to transfer our algorithm codes and implement them at INPE on INPE machines. The theoretical background aspect would enable Brazil scientists to modify and adapt the code to their needs, particularly in the Amazon region/environment.

- **Proposed Brazil collaborators**

We will need to strengthen Brazil collaboration (1:1 ratio desired) and create real partnerships with funding support, joint analysis, and publications. Yosio Shimabukuro has agreed to lead the Brazilian counterpart team to MODIS. He is also member of the IDS-Amazonia group and he has students who will be conducting field research at some of the primary test sites. The proposed or tentative list of collaborators include:

- Dr. Yosio Shimabokuro, INPE (Tapajos, Rondonia & Acre forests)
- Dr. Edson Sano, EMBRAPA (Brasilia - cerrado/agric.)
- Dr. Jose Epiphanio, INPE (Brasilia - cerrado/agric.)
- Dr. Getulio Batista, INPE (secondary regrowth sites)
- Laerte Ferreira, Ph.D. Brazil student in Huete's lab to work on cerrado to primary forest gradients.

- **Proposed Sites (with Tower and Sun Photometer support)**

Approximately 6 tower sites in primary forest; 3 in pasture; and 1 flooded as well as an additional 3 'roving towers' are planned as a result of NASA support, European-LBA support, and Brazil support.

- <u>Tapajos</u>: has extensive land cover and forest conversions; includes Santarem which will have a cluster of 3 flux towers in primary forest (65 m), cut forest site (65 m), and pasture (20 m).

- Rondonia: has extensive land cover and forest conversions.
- Manaus: has primary and secondary forest and has ongoing land dynamics studies, an active regrowth area, and has pasture chronosequence.
- Brasilia: has cerrado and agriculture (roving towers).
- Acre: has reserve and primary forest, near Bolivia border; and has secondary forest chronosequence.

• **Proposed MODLAND - Brazil field campaign**

- window of opportunity is May - July 1999.
- April and prior, there is high water and flooding and August on is the dry season and burning predominates.
- canopy access considerations/instrumentation.
- our goal is to couple ground measures with new remote sensing.

• **Action items**

- Outline of science plan will be completed Feb. 6.
- Tower implementation plan meeting in Manaus on March 9.
- LBA-wide Remote Sensing Workshop - INPE, 8-10 April.
- Science Team meeting, April 27-29, in D.C. area. The objective of this meeting will be to develop an implementation plan.

## 4. MODLAND - GLI Summary Report

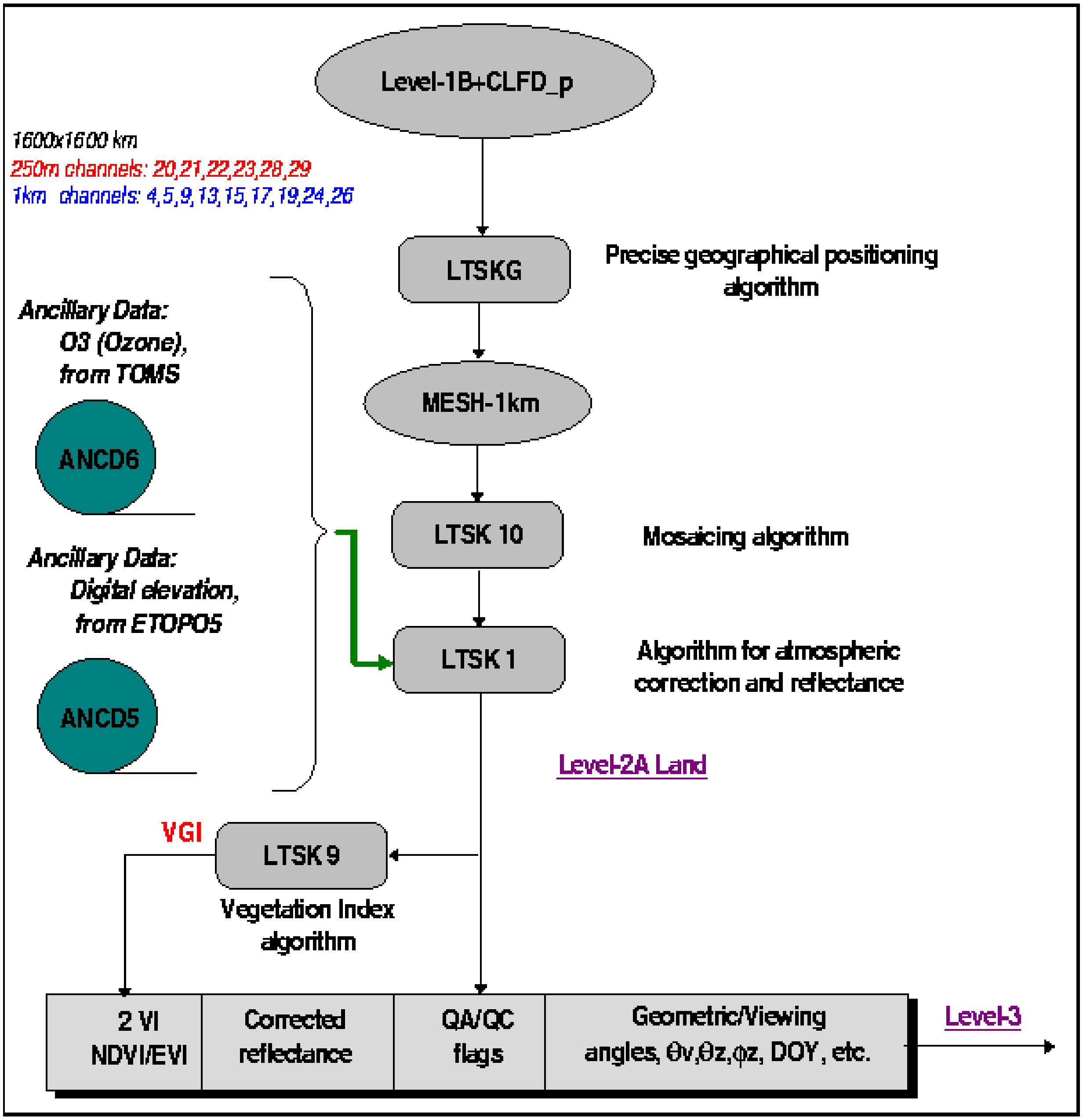
### 4.1 Overview of the GLI Mission

The Japanese-sponsored Global Imager (GLI) is an advanced Earth-remote sensing instrument to be part of the ADEOS-II satellite scheduled for launch early in 2000. NASDA has been developing the GLI sensor since 1993 for the purpose of performing medium spatial resolution visible and infrared imaging of atmosphere, land cover, and ocean color. A summary of all dedicated spectral channels, giving the central wavelengths and bandwidths (nm) can be found at NASDA's GLI website at http://www.eorc.nasda.go.jp/ADEOS-II/GLI/gli.html#tools. Of most direct interest to our TBRS group's work as part of the NASA EOS MOD-LAND team, are the 250 meter spatial resolution channels 20, 21, 22, 23, 28, and 29. By early December, 1997 we also agreed to perform the atmosphere corrections for channels 4, 5, 9, 13, 15, 17,19, 24 and 26. Those 9 bands include 'land color bands' and are to be employed at 1 km resolution.

NASDA has decided that it would be too computationally expensive to perform atmospheric correction of GLI data over land on a daily basis. They have asked us to modify the reflectances and vegetation index code to atmospherically correct only the composited data. The atmospheres group in GLI will not make aerosol corrections over land, and as a result, we have dramatically changed our algorithm approach away from the MODIS version and we will now atmospherically correct only the 15-day composited data. Atmosphere correction includes: Rayleigh scattering, ozone absorption, and water vapor, and does not include aerosols. We developed a set of computational procedures to fully solve for the radiation field at any arbitrary levels within a planetary atmosphere using the Gauss-Seidel Iteration Technique.

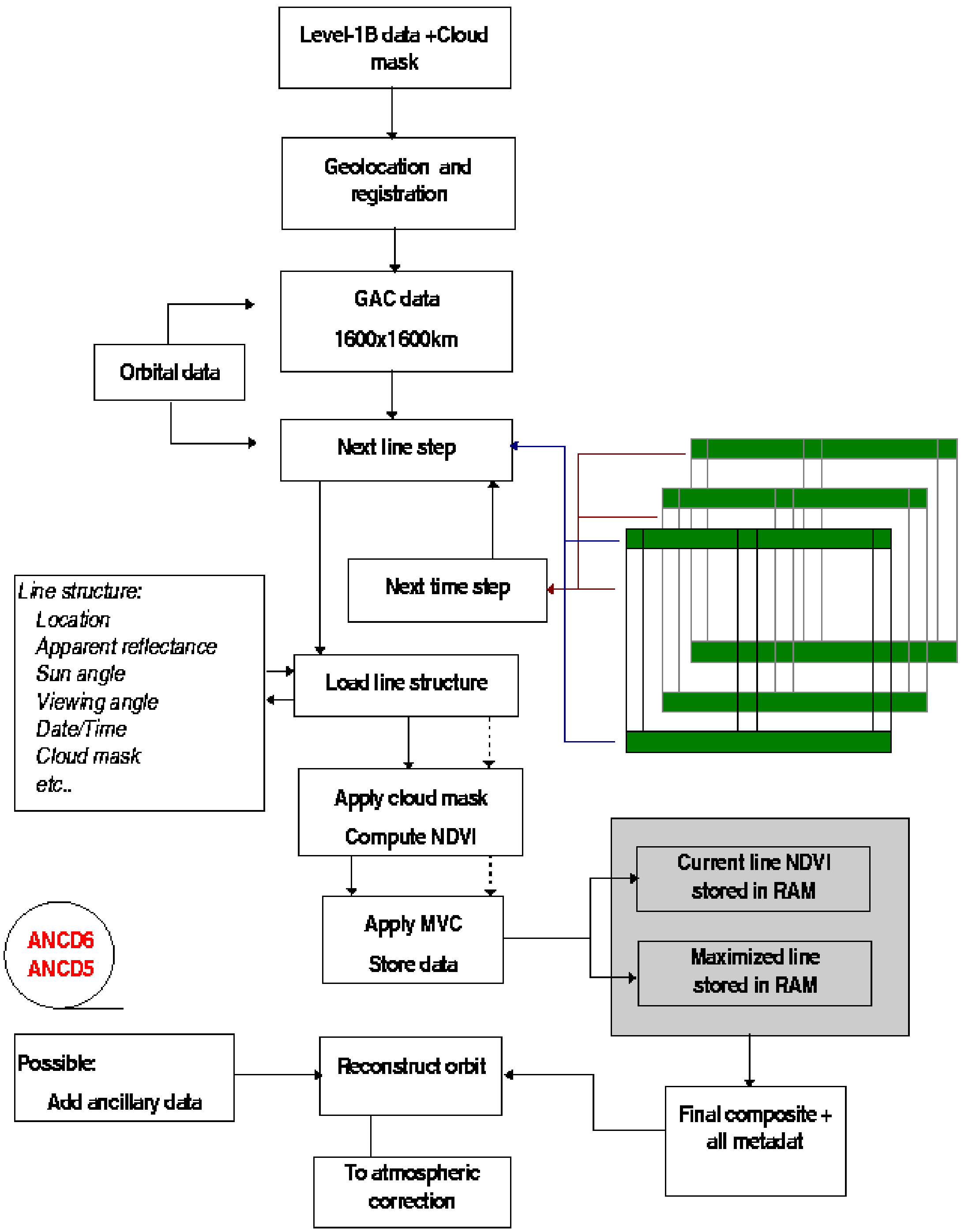
## 4.2 Development of An Operational Processing System for GLI

The first steps in creating a mechanism for doing atmosphere correction on the GLI-specific GAC and ANC input data involve: (1) exercising the full RT code for likely solar and view geometries, global ozone amounts, and global land elevations, and then; (2) storing the results from step (1) in sets of look-up tables for use in an interpolation routine designed to be a prototype module for a pixel-by-pixel calculation of expected atmosphere reflectances. The accompanying figure detail the basic approach and processing steps. As of November, 1997 our prototyping efforts along these lines have progressed to a point where we can demonstrate its speed and efficacy in computation of (a values for arbitrarily supplied individual values of sun angle and view angles on spatial scales as fine as roughly 1 square kilometer using available ETOPO5 digital elevation information


Level-1B+CLFD_p
1600x1600 km
250m channels: 20,21,22,23,28,29
1km channels: 4,5,9,13,15,17,19,24,26
LTSKG
Precise geographical positioning algorithm
Ancillary Data: O3 (Ozone), from TOMS
ANCD6
MESH-1km
LTSK 10
Mosaicing algorithm
Ancillary Data: Digital elevation, from ETOPO5
ANCD5
LTSK 1
Algorithm for atmospheric correction and reflectance
Level-2A Land
VGI
LTSK 9
Vegetation Index algorithm
2 VI NDVI/EVI
Corrected reflectance
QA/QC flags
Geometric/Viewing angles, θv,θz,φz, DOY, etc.
Level-3

Due to computational limitations, the GLI land team adopted the algorithm flow diagram in the figure below. We note that atmospheric correction will be posterior to the compositing algorithm, based on the disk and CPU load savings. Data processed at the GAIT level and cloud cover from the atmospheric (ATSK algorithms) group will serve as the input for this compositing algorithm. Meshed Global Coverage Data (GAC: 1600 x 1600 km at 1km resolution) is processed after precise geographic positioning to generate NDVI images. This MVC selection criteria is applied to the daily orbits as the data is ingested and compared to previous data stacks.

The relationship of GLI products which are relevant to the vegetation index are shown. The GLI data streams (calibration of top of the atmosphere (TOA) radiance, cloud mask, atmospheric correction and surface reflectance, vegetation indices) are set up to flow into the product algorithms in a predetermined order. For a tractable and best solution to the compositing algorithm it was logical to use the non atmospherically corrected reflectance data in combination with the cloud mask as input and use as many “good” observations as possible during a composite period.  For the first phase a half monthly and monthly composite periods were set, which satisfy both research recommendations and technical/practical limitations.


Level-1B data +Cloud mask
Geolocation and registration
GAC data
1600x1600km
Orbital data
Next line step
Next time step
Line structure:
Location
Apparent reflectance
Sun angle
Viewing angle
Date/Time
Cloud mask
etc..
Load line structure
Apply cloud mask
Compute NDVI
Current line NDVI stored in RAM
Apply MVC
Store data
Maximized line stored in RAM
ANCD6
ANCD5
Possible:
Add ancillary data
Reconstruct orbit
Final composite + all metadat
To atmospheric correction

### 4.3 GLI Validation

Several joint GLI - MODIS validation sites were proposed at the SWAMP-Val meeting in December 1997. These are the Asutralian sites listed above and the Mongolia grassland site. The GLI land team is also interested in many of the MODIS validation sites.

## 5. SCF Report

Emphasis was placed on acquiring access to vBNS line through the University's funded NSF project. We are also in the process of moving to a new and larger room for the SCF. We have also recently acquired an IDL license (through NASA) and are purchasing ENVI. Much work is needed to get sufficient storage and computing capacity for the necessary ingests of MODIS data for quality analysis and testing of the 250 m vegetation index product, which is very large volume/processing based due its fine spatial resolution (250 m). We are currently under-budgeted to meet these needs and are awaiting to see how we will connect with GSFC-TLCF via our high speed line.

Due to the 'relatively' recent demands placed on us for a complete HDF-based code delivery, we are seeking a programmer to work on this and be able to maintain the code and provide updates and modifications as the need arises. Prior to this we had assumed that only the science code would be provided and delivered by us. Brad Castalia, our systems person, recently visited Montana for software training and programming help with Joe Glassy.

## 6. Anticipated Future Action

The tasks for the coming half year include further development of the vegetation index compositing algorithms, a more comprehensive error and accuracy analysis assessment, and a comprehensive validation package in place. Specific tasks and research will focus on:

- completing the 1 km AVHRR compositing (June 1995 data) code development for orbit stitching and for cloud mask/land mask as well as integration with current composite schemes. This will help to prototype 1 km VI on a continental scale,

- prototype and analyze MODIS vegetation index composite results with SeaWifs data (see IGARSS 1998 abstracts). Also check for artifacts of the enhanced vegetation index (EVI) on a global basis,

- setting up QA analysis procedures and develop tools for automated QA and in depth analysis of MODIS algorithms and their product,

- the use of a historical BRDF data base in combination with vegetation index composite scenario; to be tested on 8 km AVHRR (test alternative compositing algorithms),

- sun and view angle correction with BRDF models at climate modeling grid (CMG) level,

- fine tuning algorithms for version 2.1 and anticipate potential code replacement scenarios for post launch code updates.

## 7. Publications


Miura, T., A.R. Huete, W.J.D. van Leeuwen, K. Didan. 1998. Vegetation Detection through Smoke-filled AVIRIS Images: An assessmment Using MODIS Bandpasses. J. Geophys. Res., SCAR-B special Issue (in press).

Huete, A.R., H.Q. Liu, W.J.D. van Leeuwen, K. Didan. 1997. The use of Vegetation Indices in Forested Regions: Issues of Linearity and Saturation. J. Geophys. Res., EOS-AM special issue, (Submitted).

van Leeuwen, W.J.D., A.R. Huete, T. W. Laing, 1997. Global Vegetation Index Compositing Approach for MODIS-EOS. J. Geophys. Res., EOS-AM special issue, (Submitted).

van Leeuwen, W.J.D. Trevor W. Laing, and Alfredo R. Huete, 1997. Quality Assurance of Global Vegetation Index Compositing Algorithms Using AVHRR Data. IEEE- IGARSS'97, Singapore (pp 1-3; in press)

Huete, A.R., H. Liu, W.J.D. van Leeuwen, 1997. The Use of Vegetation Indices in Forested Regions: Issues of Linearity and Saturation. IEEE-IGARSS'97, Singapore (pp 1-3; in press)

W.J.D. van Leeuwen, A.R. Huete., K. Didan and T. Laing, 1997. Modeling bi-directional reflectance factors for different land cover types and surface components to standardize vegetation indices. 7th Int. Symp. Phys. Measurements and Signatures in Remote Sensing, Courcheval. (pp 1-8; in press)

Sano, E.E., Moran, M.S., Huete, A.R., and  Miura, T. (1997). "C- and Multi-angle Ku-band Synthetic Aperture Radar Data for Bare Soil Moisture Estimation in Agriculture Areas". Remote Sens. Environ. (in press).

de Lira Reyes, Gerardo, 1997, "Spatial and Seasonal Variations Along the U.S.-Mexico Border: An Analysis With Landsat Thematic Mapper Imagery", 230pp. (Ph.D Dissertation)

SUBMITTED IGARSS'98 ABSTRACT:

Evaluation of the MODIS vegetation index compositing algorithm using SeaWiFS data; Wim J.D. VAN LEEUWEN, Alfredo R. HUETE, Trevor W. LAING, Tomoaki MIURA

Vegetation index data were composited in space and time to monitor vegetation changes in a spatial continuous fashion. Sixteen days of SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data (surface reflectance data corrected for Rayleigh scattering, Ozone and water vapor) were composited to prototype and test the MODIS (MODerate resolution Imaging Spectroradiometer) algorithm for "standardized" MODIS vegetation indices. The SeaWiFS was tilted 20°, preventing nadir looks of the Earth's surface. However, the MODIS algorithm applies a pixel-based Bidirectional Reflectance Distribution Function model (BRDF; Walthall) to obtain nadir- equivalent reflectance values at the prevalent solar zenith angle. The nadir-equivalent reflectance values were used to compute the normalized difference vegetation index(NDVI) and the enhanced vegetation index (EVI). A back-up algorithm (Maximum Value Composite; MVC) was applied if insufficient data was available to invert the BRDF model. To apply the MODIS compositing algorithm, a cloud mask was developed for the SeaWiFS data using a reflectance threshold for the visible bands. A land-water mask was used to retain only the land pixels. The anisotropic behavior of both vegetation indices was examined for a range of vegetation types by extracting the reflectance and view angle data for each day during a composite period. Anisotropy was found to be affecting the vegetation indices quite strongly, supporting the effort to standardize the VIs to nadir view angles. A mask indicating the quality of the vegetation index data was also presented to indicate the compositing methodology and the usefulness of the vegetation index data. The MODIS algorithm needs accurate cloud information to screen out the cloud affected pixels. The classical MVC method was computed to quantify the difference between the MODIS and MVC algorithms and establish a relationship for continuity purposes that will allow for comparisons of archived historical MVC-NDVI data with NDVI data from the current sensors.

Terrestrial Biosphere Analysis of SeaWiFS data over the Amazon Region with MODIS and GLI Prototype Vegetation Indices; Alfredo HUETE, Dana KEROLA, Kamel DIDAN, Wim J.D. VAN LEEUWEN, Laerte FERREIRA

A stream of multitemporal SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data was extracted and analyzed over the Amazon region and surrounding land-community validation sites representing a wide range of vegetation conditions. The raw data was atmospherically-corrected for molecular scattering and ozone absorption with a Gauss-Seidel iteration technique and the resulting bidirectional reflectances were used to compute various ratio-based, orthogonal-based, aerosol resistant, and enhanced vegetation indices. Results were analyzed for both the tilted 20° look angle of SeaWifs and the extrapolated nadir (0°) look using a BRDF model. Various vegetation indices were analyzed to evaluate their usefulness for carbon modeling studies, discriminating canopy structure variations, and in depicting land-use/ land cover changes in semi-arid cerrado, and high biomass rainforests (primary and secondary). Previous studies have indicated problems with vegetation indices in the Amazon region with respect to chlorophyll-saturation and asymptotic vegetation index behavior. The objectives of this work were to (1) prototype gridded vegetation map products for the EOS- MODIS (MODerate Resolution Imaging Spectroradiometer) and ADEOS- Global Imager (GLI) sensors; (2) assess the utility of multiple vegetation indices over continental data fields; (3) analyze sensitivities over a global range of vegetation conditions (cerrado to rainforest); and (4) assess the relative usefulness of SeaWifs data in depicting canopy structural and compositional differences across the Amazon region. We found the SeaWifs data to be highly useful in mapping the vegetation cover of the Amazon region. The various vegetation indices yielded very contrasting results in their ability to discriminate vegetation and land-use differences. We conclude that multiple indices are required to fully characterize the spatial/temporal variations of the Amazon region.

# APPENDIX A

## SWAMP- Validation Workshop, Dec. 3-5, 1997; College Park, Maryland

**Topic: Biophysical/Vegetation Measurements**
**Alfredo Huete & Betty Walter-Shea**

The purpose of this working group was to discuss the relevant issues in need of attention to initiate a working design and protocol for the validation of the LAI, FPAR, Land Cover, NPP, and Vegetation Index products. The goal is to develop a set of “standardized” procedures for the validation of vegetation-related satellite products across a global range of biomes, over the entire phenologic cycle, and within expected sun-target-sensor conditions. A standardized methodology is considered essential for cross-site comparability. Crucial to all of the measures discussed below is the need for ground to air to satellite registration with GPS.

### A. FPAR Product:

- Discussions on validation of the FPAR product focussed on the need for field measures of both fraction of PAR *intercepted* (FIPAR) and fraction of PAR *absorbed* (FAPAR). We decided to strive for diurnal (daily) measures of FPAR with the minimum requirement being that instantaneous measures be made close to time of overpass and over a range of sun angles, bracketing the time of the satellite overpass.

- Justification: since interception and absorption of incoming PAR varies throughout the day, FAPAR measures at various sun angles enables: (1) better integration into daily FAPAR - and photosynthesis/carbon uptake; and (2) standardization of FAPAR measures to constant sun angles, when spatial/temporal comparisons of instantaneous FAPAR are desired.

- Instrumentation: the primary instruments required are ceptometers and line quantum sensors. A quantum sensor is also needed in an open area. Both instruments need calibration and cross-calibration to a standard reference and caution is needed with their sun angle dependency on calibration.

- Sampling design: this was not discussed yet. Sampling schemes will vary with land cover type and site heterogeneity.

## B. LAI Product

- We defined leaf area index (LAI) as one-half the total leaf area (one-sided) per unit area of ground surface. We further distinguished between the LAI of broadleaf canopies (one-sided leaf area) and the LAI of needleleaf canopies (the projected area). We recommend that measures of LAI be separated into green LAI (active canopy component) and non-green LAI. We note that the non-green component may have large effects on the remotely-sensed interpretation of green LAI.

- Instrumentation: direct measures of LAI involve destructive harvesting and associated allometric equations. More indirect measures include use of ceptometers and Li-Cor LAI-2000. Indirect methods measure light transmittance and relationships of light transmittance with LAI are land cover dependent and ‘corrections’ are generally needed.

- Sampling design: in most biomes, LAI measures will be made through indirect means (e.g. LAI-2000). The indirect measure will generally allow for more rapid and extensive measures of LAI at a footprint scale of approximately 0.1 - 1.0 kilometer. The indirect measure, however should be referenced to a more accurate and validated, destructive and/or allometric, procedure. Each biome and land cover class will have an existing and recognized procedure for ‘point-based’ LAI measures. Coupling the Li-Cor 2000 to such a reference will allow for the most accurate LAI measures to be extended from the meters footprint to the kilometer scale.

- Additional measurements required for the LAI product include:
  - characterization of foliage clumping, such as shrub and pixel area,
  - overstory and understory LAI need to be measured and discriminated,
  - measurements of both green (active) LAI and total (green + non-green) LAI are needed.

- Complimentary parameters and measures that are ***desired*** to compliment the LAI/FPAR and VI products:
    - vegetation cover
    - leaf optical properties
    - canopy background optical properties (soil, litter, snow, water, etc..)
    - LAD (estimate of leaf angle class)
    - phenology
    - species composition
    - height
    - understory/overstory
    - wet/dry
    - non-photosynthetic vegetation (litter, woody stems)

## C. Vegetation Indices

- Vegetation Indices are unitless radiometric measures that depict spatial/temporal variations in vegetation photosynthetic activity, canopy structural variations, and vegetation seasonal, inter-annual, and land-use changes. Validation of this product is coupled to biophysical vegetation measurements as well as radiometric measurements of canopy reflectance properties. Since it is the output of the VI that must be validated, we need to ensure that the variance or invariance in VI values correspond to real, surface-related canopy behavior. Thus, measurements required are similar to those of the FPAR and LAI products. As with the FPAR product, VI's exhibit pronounced diurnal variations and require measurements over a range of sun angles.

- Additional measurements include,
    - canopy reflectance measurements over the canopy and 'under' the atmosphere (~150 m above canopy; e.g., light aircraft),
    - canopy transmittance measures in the visible and near-infrared to derive measures of the optical thickness (thinness) of the canopy (LAI, LAD, and foliage clumping determine to a large extent the density and optical depth of a plant canopy),
    - measure background optical properties

## D. Land Cover and NPP Products

- Land Cover and NPP products. Not much time was spent on these vegetation-related products. The land cover product has its own protocol for sampling and survey. The NPP product validation will focus mostly on the fluxnet towers and $CO_2$ flux measures, which was a separate working group at this workshop. In our group, we identified the following measures in support of the NPP product:
  - measures of above-ground biomass (dry weight) production, including bole production, litter production, etc.,
  - measures of below ground biomass production (roots), however there is currently no commitment or resources for this.

**E. Timing and Frequency:**

- Measures of LAI, FPAR, and VI's are needed over four critical periods,
  - during green-up,
  - maximum greenness (peak greenness),
  - brown dry-down, and
  - senescent phases.
- If resources are available, we would also prefer measures in between these critical periods as well.

**F. Sampling Design**:

Not enough time was available to discuss this to any depth. Spectral vegetation indices were identified as one way that point-based measurements could be extrapolated to 10 km by 10 km maps and footprints. Site heterogeneity issues are expected to be pronounced. Most sites will have variation in the parameters due to differences in topography, soils, species composition, age structure of the canopies, etc.. We expect to identify vegetation canopy types and variations with aerial photography and design a sampling strategy which seeks both uniformity and cross-site variations for the measurements. Sampling statistics and scaling issues (extrapolate point measurements to canopy and landscape scales) need to be incorporated in the final sampling designs. The use of GPS in all sampling schemes is critical.

## G. Calibration:

The Li-Cor LAI devices, ceptometers, line quantum sensors, and radiometers will require absolute and relative calibration on a periodic basis. A 'traveling standard', which can be housed in a calibration lab and shipped to field experiments, was proposed to maintain a wide array of sensors calibrated. Kurt Thome offered his lab in Arizona for calibration.

## H. Validation Core Sites

Our core sites have the priority of possessing "Towers" and co-located sun photometers, taking advantage of the flux tower and sun photometer networks.

| | |
|---|---|
| - ARM CART site, Oklahoma | agriculture, mixed |
| - Wisconsin Fluxnet | grassland/forest |
| - Walker Branch, Tennessee | mixed forest |
| - Beltsville, Maryland (USDA) | agriculture |
| - H.J. Andrews (new tower location) | conifer |
| - Jornada/ Sevilleta (LTER) | desert shrub, grass |
| - Konza (LTER) | grassland |
| - Harvard Forest (LTER) | deciduous forest |
| - Maricopa farm, Arizona (no tower) | agriculture, desert |
| - Florida slash pine/Fluxnet | pine |
| - Howland, Maine | deciduous forest |
| - Glacier Natl. Park, Montana | conifer |
| - SALSA campaign, Arizona/Mexico | shrub/grass/mt. conifer |

The following are foreign tower sites:

| | |
|---|---|
| - Mongu, Zambia | Kalahari woodland |
| - Skukazu, RSA | Savanna woodland |
| - Uardry, Australia | semi-arid shrub |
| - Ubsu Nur, Mongolia | grassland |
| - Tapajos, LBA | broadleaf forest |
| - Rondonia, LBA | broadleaf forest |
| - Brasilia, LBA | cerrado |
| - BOREAS tower sites?? | Conifer |
| - Krasnoyarsk, Russia?? | Forest/tundra |

## I. Light aircraft plan (MQUALS)

- Although not discussed in our breakout group due to lack of time, a light aircraft-based plan was proposed for consideration in overall validation activities of this group. Attached below is the purpose and rough sketch of such a package.

  - extend point-based reflectance measures to larger footprints (1 km) and to all canopy types (forest, grass, etc..)
    - 150 m to 300 m AGL
    - thin to no atmosphere

  - a consistent and mobile radiometric package
    - transfer radiometers coupled to MCST calibration
    - instrumentation simple and stable
    - easily transported to other field sites, campaigns, incl. SAVE (Africa) and LBA (Brazil)

  - versatile, low cost, rapid deployment
    - can vary view angles (2 to 3 exotechs flown with pointing capability to bracket MODIS ‘look angles’
    - can bracket sun angles (two flights at two sun angles)

  - in conjunction with and coupled to fAPAR and LAI validation
    - characterize canopy reflectance over 1 km footprint at various view and sun angles.
    - characterize wide range of canopy types and conditions in consistent manner with same radiometric package.